FUSION: Physics of a Fundamental Energy Source

Fusion events release the energy that powers the sun and other stars. To release appreciable fusion energy requires high temperature plasmas confined for times long enough for sufficient fusion reactions to occur. The results of research in nuclear and plasma physics are being used to create controlled fusion on earth as a possible source of energy to supplement other sources in meeting the world's needs. Using the visual theme of the Sun and the Earth as a backdrop, this chart explores fusion – its relationship to other sources of energy, the nuclear and plasma physics of fusion, heating and confining plasmas for fusion, and some results of fusion research.

Energy Sources and Conversions

Modern society relies on the availability of many forms of energy and must convert these into useful forms. In most power plants, thermal energy is produced by energy-releasing reactions such as chemical, fission, and – in the future – fusion reactions. The thermal energy is then converted to other useful forms in a cycle following the basic laws of thermodynamics. Limits in the efficiency of these conversion processes are formalized in the 2nd Law of Thermodynamics; invariably waste energy and waste material are produced. The energy generated per kilogram of fuel, which is typically much larger for the nuclear processes, is based on the reactions and inputs shown on the chart. In the most likely first-generation fusion plant, the reaction will actually be the fusion of deuterium, which is plentiful on the earth, and tritium. The tritium will be produced in the same reactor, since lithium absorbs neutrons from this "D-T" reaction and splits into tritium and helium. Thus deuterium and lithium are the actual input materials.

How Fusion Reactions Work

The equation $\Delta E = (m_i - m_f)c^2$ states that kinetic energy is released by the mass differences of reactants (m_i) and products (m_f). The binding energy of a nucleus is the difference in the mass of the nucleus compared to the sum of the masses of its constituent nucleons (protons and neutrons); a larger binding energy represents a greater difference. The shape of the graph of binding energy per nucleon shows that combining low mass elements (fusion) yields a nucleus with greater binding energy per nucleon and thus releases energy. For larger mass elements (above about mass 62 u), splitting the nucleus into smaller parts (fission) gives less massive nuclei thereby releasing energy. Because the curve is steeper on the "fusion" side (masses below 62 u) than the "fission" side, there is more energy released per nucleon in fusion than in fission. Shown schematically are some characteristics of two important fusion processes: the p-p fusion chain, which is the primary method for releasing energy in the sun; and the D-T reaction, which will probably be used in first-generation fusion power plants. The Fusion Reaction Rate Coefficient graph shows a strong dependence on energy (ion temperature). The high temperatures shown on this graph are necessary because the nuclei must approach to within about 10^{-15} m to fuse, so that the attraction from the residual strong interaction between the nuclei overcomes the electrical repulsion between the protons. The difference in the rates between these two fusion reactions shows why the D-T process, rather than the sun's process, is being explored for earth-based applications.

Plasmas - the 4th State of Matter

Plasmas, collections of freely moving charged particles, occur in many contexts, spanning an incredible range of densities and temperatures. Plasma science provides one of the cornerstones for our knowledge of the Sun, the stars, the interstellar medium, galaxies, neon lighting, lightning, the aurora and techniques for controlling the fusion process. Plasmas are influenced by the long-range electrical interactions of ions and electrons and by the presence of magnetic fields, either applied externally or generated by current flows within the plasma. The dynamics of such systems are complex and must be well understood for the development of fusion energy.

The Conditions for Fusion

Refinements in the techniques for heating and confining plasmas are necessary to achieve controlled fusion. For the deuterium-tritium plasma which must be at temperatures of about 10^8 K, the two most promising confinement techniques are magnetic and inertial. The tokamak, a toroidal device comprising a hollow doughnut-shaped vessel through which magnetic fields twist, is the most common magnetic confinement device under study. In inertial confinement, intense lasers or ion beams compress a pellet to extremely high plasma densities and temperatures which will allow significant amounts of fusion in the short time the imploding pellet is confined by its inertia.

To achieve controlled fusion, a plasma at a given temperature must be confined at a high enough density for a sufficiently long time. This criterion is expressed in terms of the confinement quality: the product of the plasma density and energy confinement time. Recent experiments have produced plasmas with either confinement time, the plasma density, or plasma temperature at values near or exceeding those needed for self-sustaining controlled fusion, but all three have not been achieved simultaneously.

About the Contemporary Physics Education Project (CPEP)

CPEP Sites on the World-Wide Web

Fusion Group Home page: FusEdWeb.pppl.gov/CPEP/Chart.html
CPEP Home Page: www.CPEPweb.org

Many other sites of interest can be reached from these award-winning sites.

Selected CPEP Products

CPEP materials can be ordered from:

Science Kit
P.O. Box 5003
Tonawanda, NY 14150-5003
USA

Tel: (800) 828-7777 or (716) 874-6020
Fax: (800) 828-3299 or (716) 874-9572
Web: www.ScienceKit.com

Fusion / Plasma Physics Products

"Fusion - Physics of a Fundamental Energy Source"

Cat. No.	Description	2001 Price
71958-00	Large Chart / 150 × 107 cm	$22
71958-02	Poster / 75 × 53 cm	$11
71958-32	Laminated Poster	$17
71958-01	Notebook Charts 30-pack/41 × 28 cm	$21
71958-22	Laminated Notebook Charts (Placemats) / Set of 6	$21
71958-41	Color Transparency of Chart	$4
46144-00	Fluorescent Light Demo Kit	$145
	Includes half-coated, half-clear bulb to see the plasma. Accessories required; see Science Kit Catalog	

Combination Sets of all 3 CPEP Charts

(1 each Fusion, Nuclear, and Particles)

Cat. No.	Description	2001 Price
71966-00	3 Large Charts / each 150 × 107 cm	$50
71966-01	3 Posters / each 75 × 53 cm	$25
71966-32	6 Placemats / 2 of each / 42 × 29 cm	$21
71966-41	3 Color Transparencies	$10

Nuclear Science Products

Cat. No.	Description	2001 Price
71960-00	Large Chart / 150 × 107 cm	$22
71960-02	Poster / 75 × 53 cm	$11
71960-22	Laminated Poster	$17
71960-30	Notebook Charts 30-pack/41 × 28 cm	$21
71960-32	Laminated Notebook Charts (Placemats) / Set of 6	$21
71960-41	Color Transparency of Chart	$4
71960-04	Teacher's Guide	$20

Particle Physics Products

Cat. No.	Description	2001 Price
71957-00	Large Chart / 150 × 107 cm	$22
71957-01	Poster / 75 × 53 cm	$11
71957-22	Laminated Poster	$17
71957-31	Notebook Charts 30-pack/41 × 28 cm	$21
71957-32	Laminated Notebook Charts (Placemats) / Set of 6	$21
71957-41	Color Transparency of Chart	$4
71957-40	Activities Packet with Worksheets and Transparency	$10

For USA orders, add 10% for shipping/handling, minimum $4 (overseas, please contact Science Kit for quote). AR,AZ,CA,NC,SC,WA add sales tax. Check, money order, MasterCard, Visa accepted.